N91-27297

Program 13 Experimental Study of the Viscoplastic Response of High Temperature Structures

Marshall F. Coyle and E.A. Thornton

Objectives

The basic objective of this research program is to investigate experimentally the viscoplastic response of thermal structures for high speed flight. An additional objective of the experimental program is to provide high quality data for validation of finite element analysis using unified viscoplastic constitutive models.

EXPERIMENTAL AND COMPUTATIONAL STUDIES OF THERMOVISCOPLASTIC PANELS

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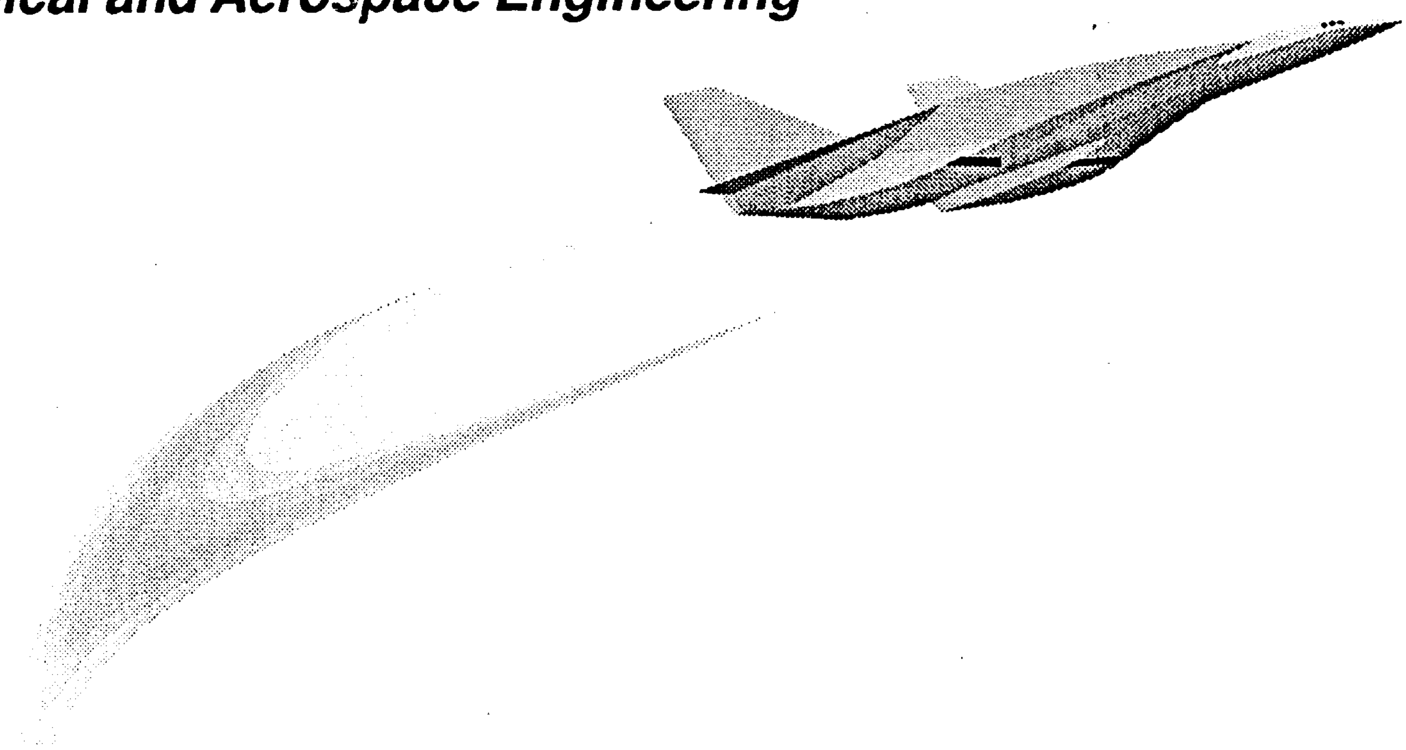
Mechanical and Aerospace Engineering



EXPERIMENTAL AND COMPUTATIONAL STUDIES

OF THERMOVISCOPLASTIC PANELS

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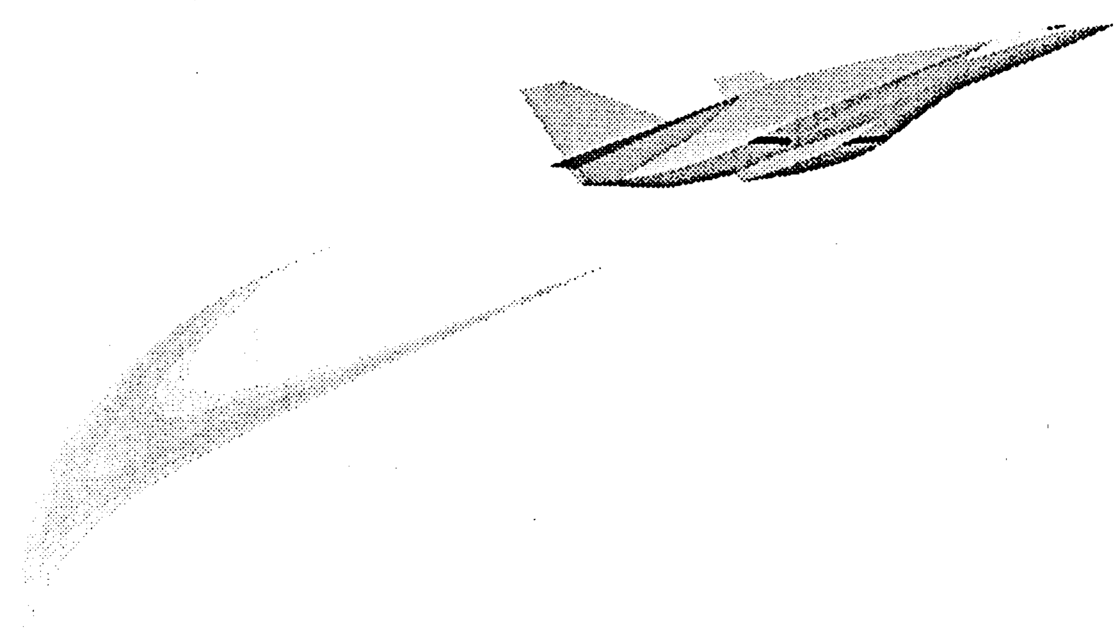
Abstract

The presentation describes computational and experimental studies of the thermal-structural behavior of thin panels subjected to localized heating. Three research tasks are described: (1) development of a finite element thermoviscoplastic computational approach, (2) experimental determination of material parameters for Bodner-Partom constitutive models of panel materials, and (3) experimental study of "Heldenfels" panels subjected to intense local heating. Recent research progress in each task is reviewed. Development of a new experimental set-up for the panel tests is described in detail and preliminary test results are presented. Plans for future research are highlighted.

RESEARCH OBJECTIVES

- Investigate Thermoviscoplastic (TVP) response of thin panels subject to intense local heating.
- Evaluate finite element Thermal-Structural analyses with unified TVP constitutive models by comparison with experimental data.



<u>THERMOVISCOPLASTIC RESEARCH PROGRAM</u>

- FINITE ELEMENT TVP ANALYSIS

  J. D. KOLENSKI

- BODNER-PARTOM CONSTITUTIVE MODELS

  MARK A. ROWLEY

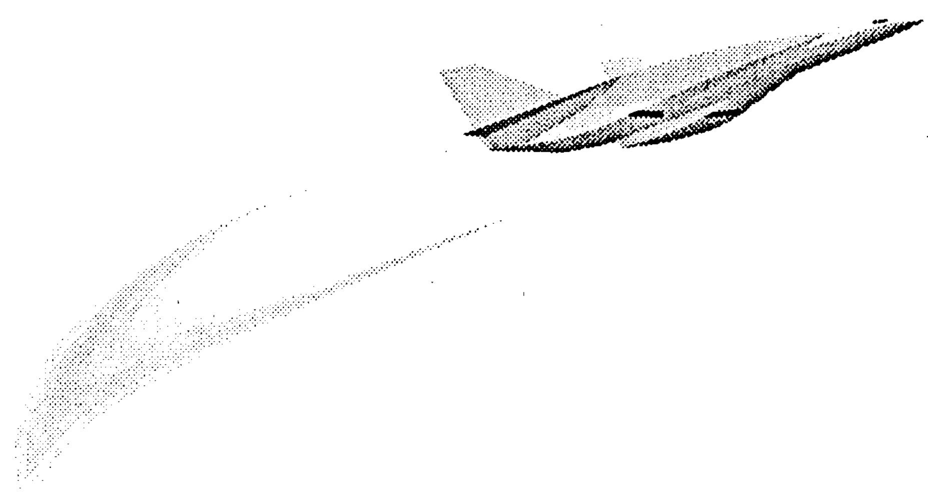
- THERMAL-STRUCTURAL TESTS OF PANELS

  MARSHALL F. COYLE

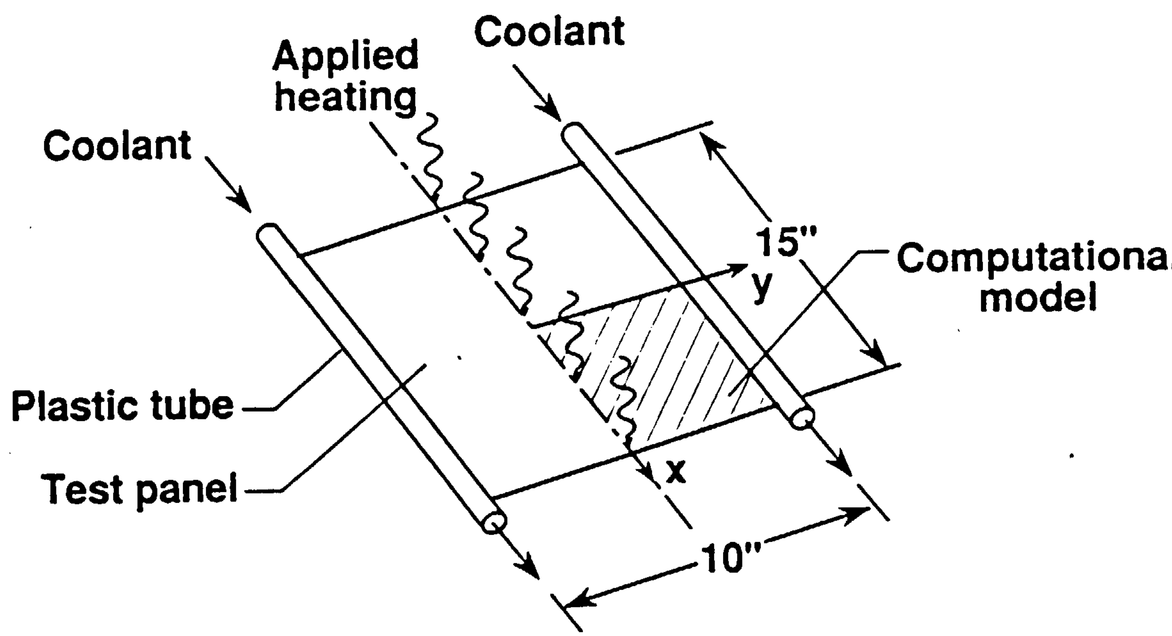
FINITE ELEMENT THERMOVISCOPLASTIC ANALYSIS

FINITE ELEMENT THERMOVISCOPLASTIC ANALYSIS

- ASSUMES QUASI-STATIC THERMAL STRESS BEHAVIOR
  - -Neglects Thermal-Mechanical Coupling in Energy Equation
  - -Neglects Inertia Forces in Equations of Motion
- ASSUMES PLANE STRESS
- USES BODNER-PARTOM CONSTITUTIVE MODEL
- IMPLEMENTS EQUATIONS IN RATE FORM AND USES TIME-MARCHING ALGORITHM



HASTELLOY-X PANEL

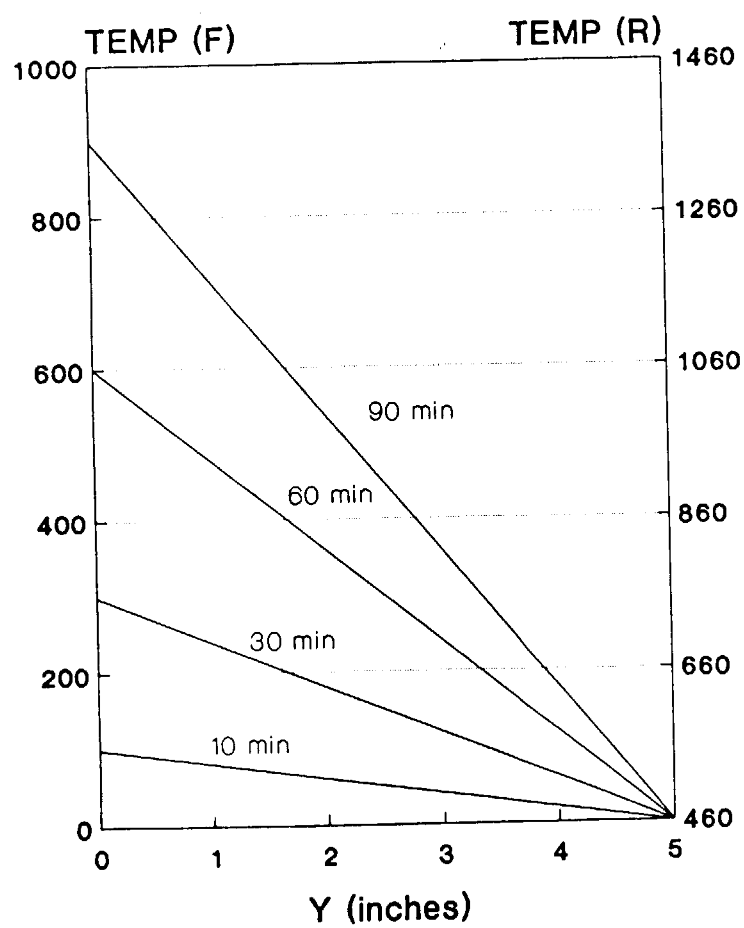


Finite Element Meshes:

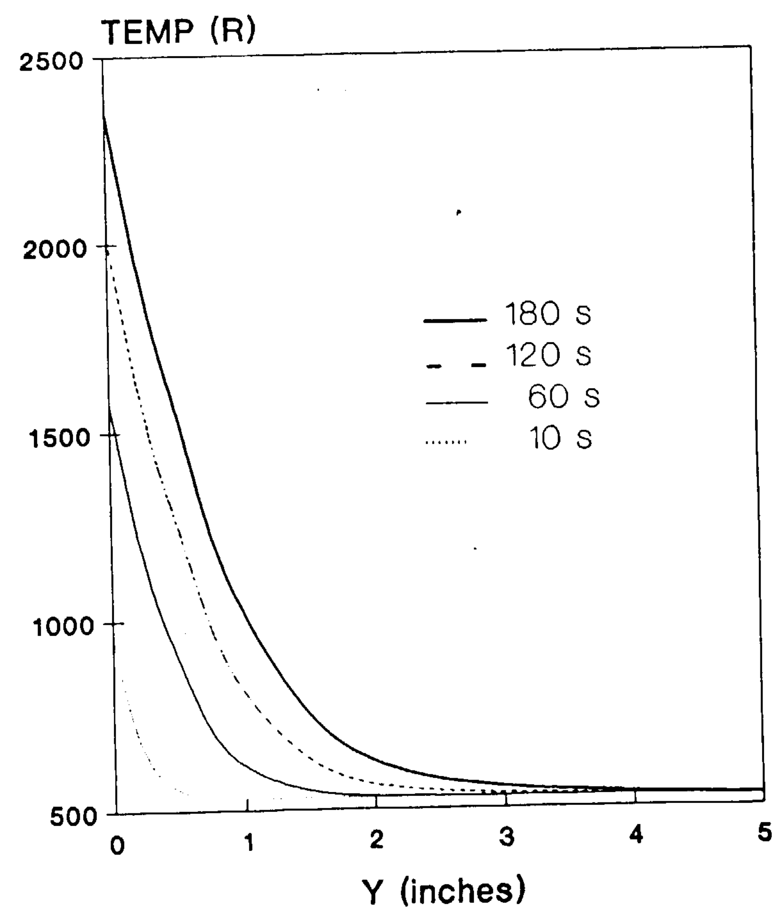
	Slowly Heated	Rapidly Heated
Nodes:	176 uniform	187 stretched
Elements:	150 quads	320 triangles

HASTELLOY-X PANEL TEMPERATURES

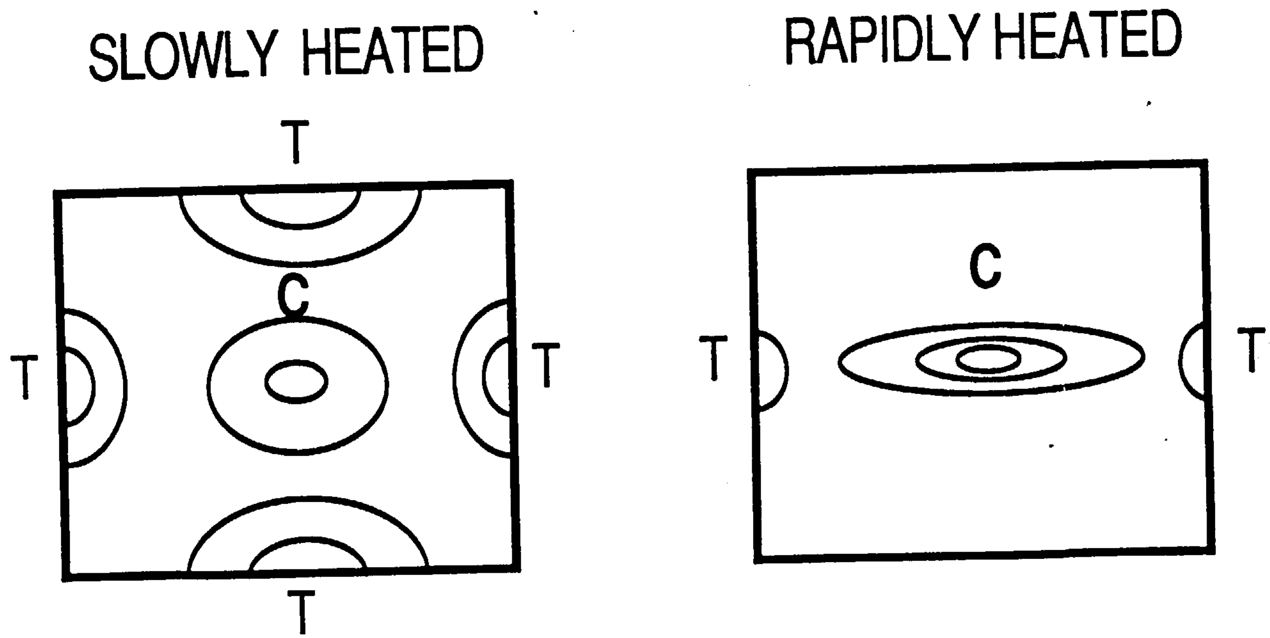
SLOWLY HEATED



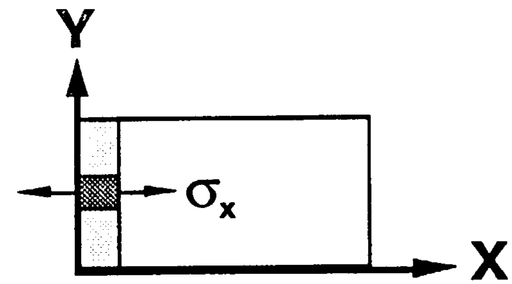
RAPIDLY HEATED



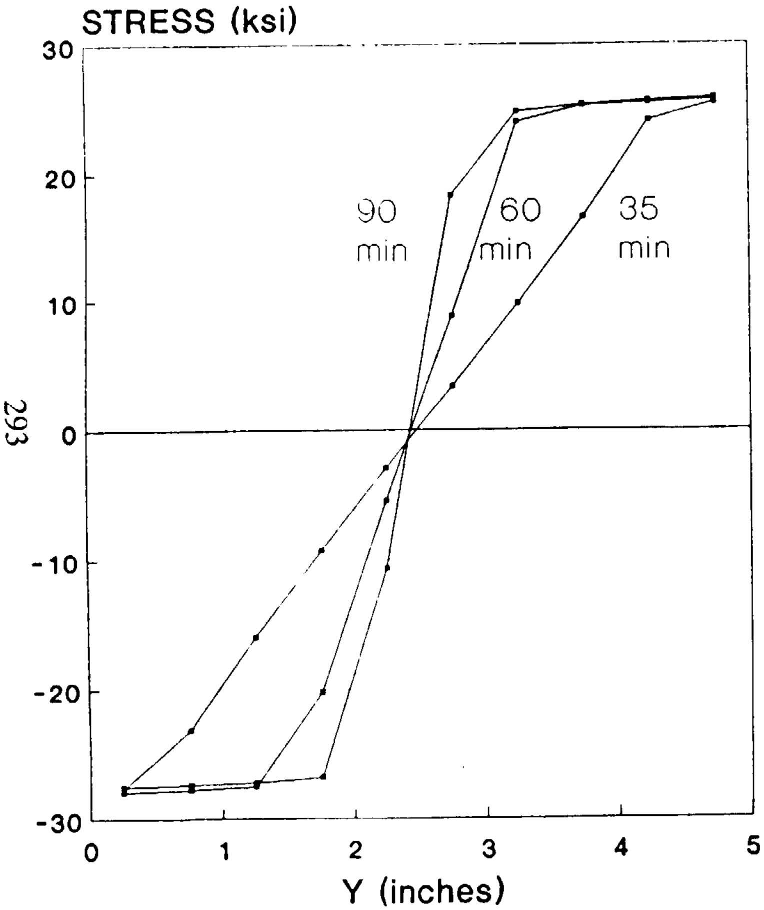
YIELDED REGIONS



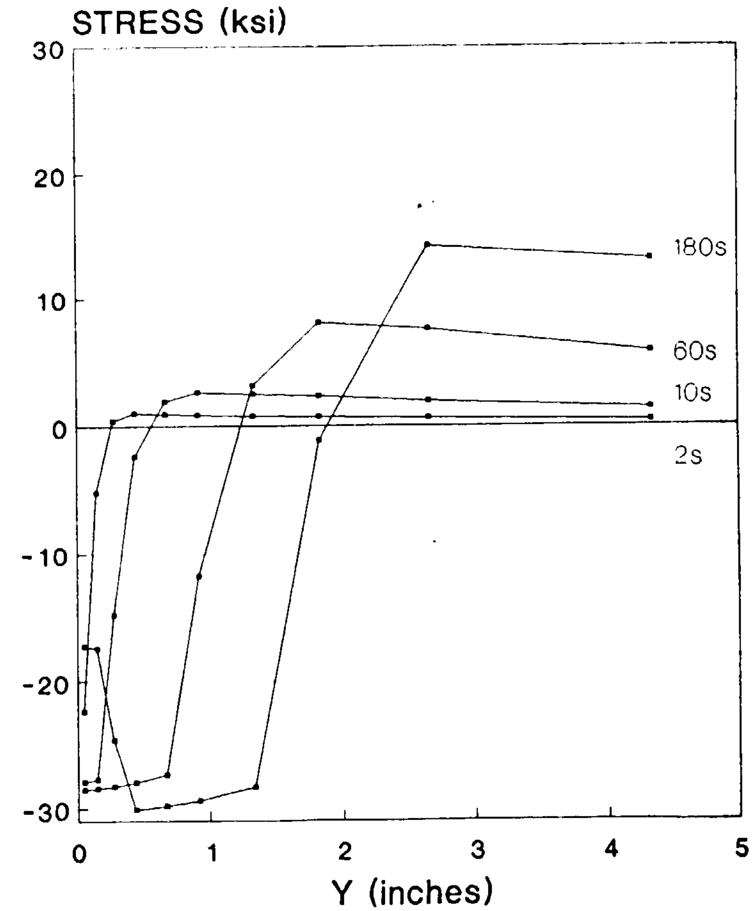
RECTANGULAR PANEL INELASTIC STRESSES



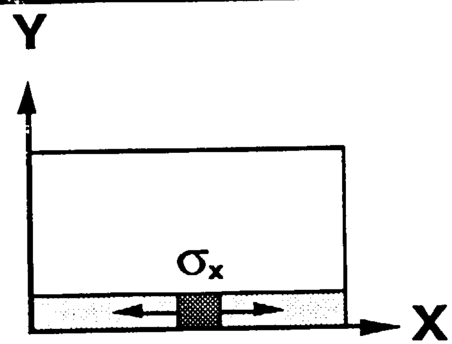
Slowly Heated



Rapidly Heated



RECTANGULAR PANEL INELASTIC STRESSES



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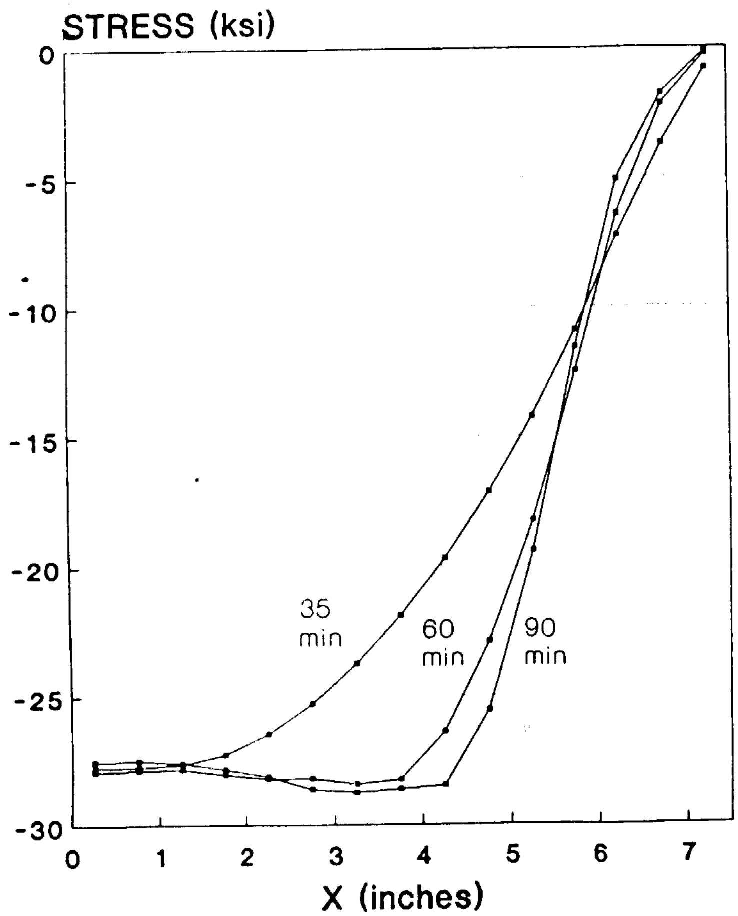
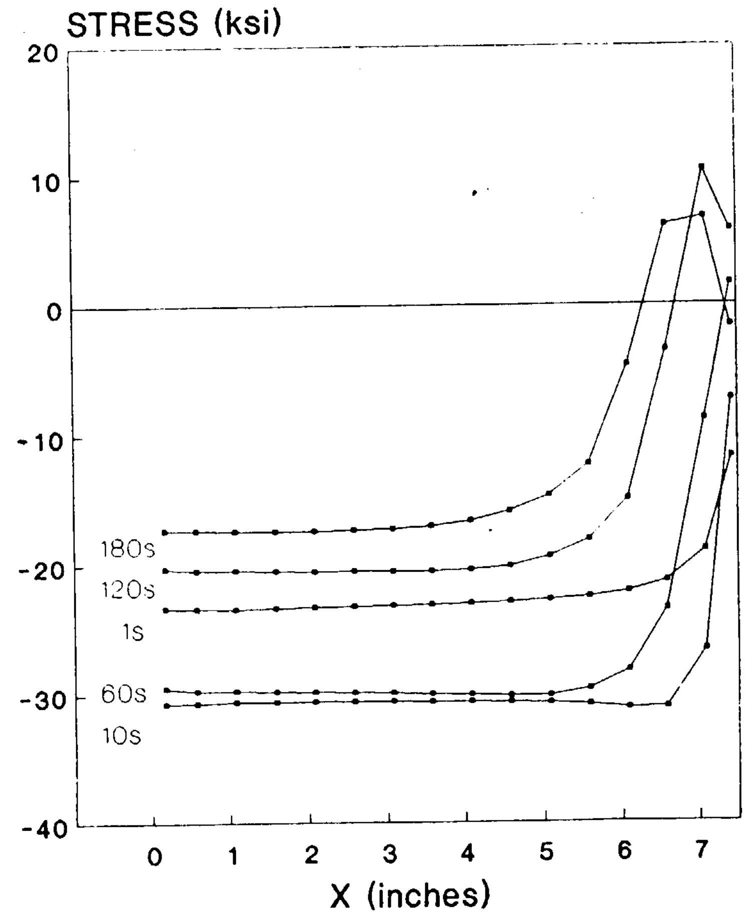
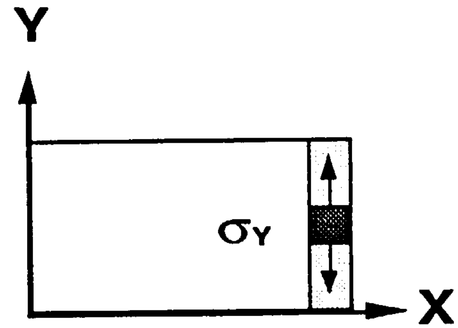


Rapidly Heated



RECTANGULAR PANEL INELASTIC STRESSES



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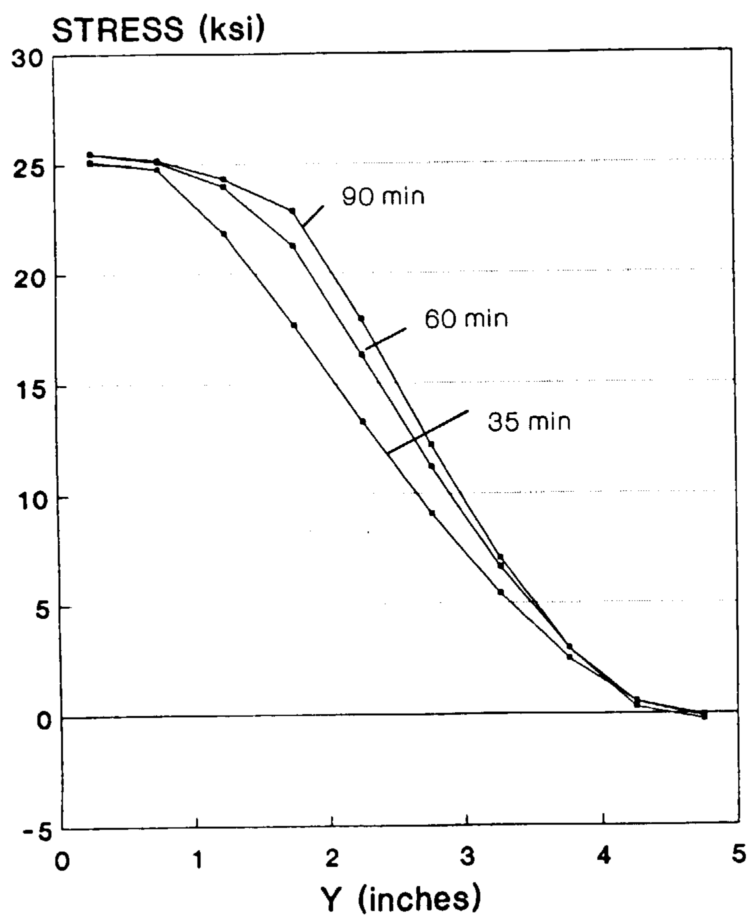
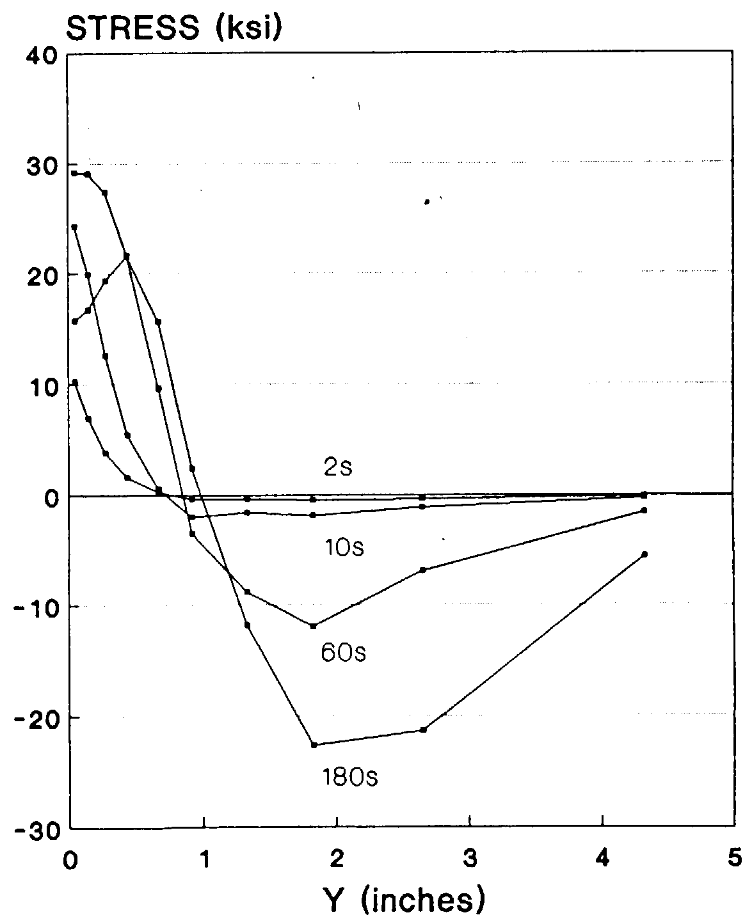


Rapidly Heated



CONCLUSIONS FROM PLANE STRESS COMPUTATIONS

- TEMPERATURE RISE TIMES AND LEVELS SIGNIFICANT
- FOR RAPID TEMPERATURE RISES:
  - -HIGHER YIELD STRESSES FROM STRAIN-RATE EFFECTS
- AT ELEVATED TEMPERATURES:
  - -MATERIAL YIELD STRENGTH AND STIFFNESS DEGRADE RAPIDLY
  - -PRONOUNCED PLASTIC DEFORMATION

EXTENSION OF COMPUTATIONS TO PLATE BENDING

- FINITE ELEMENT PLATE BENDING
  WITH VON KARMAN PLATE THEORY
- REPRESENT INITIAL PANEL DEFORMATIONS AND THERMAL BUCKLING
- BODNER-PARTOM CONSTITUTIVE MODEL
- QUASI-STATIC RESPONSE
- THERMAL AND MECHANICAL LOADS
- TVP RATE FORMULATION

FINITE ELEMENT FORMULATION

$$[K_m + K_b + K_g(N)]\{\dot{\delta}\} + [K_g(\dot{N})]\{\delta\} = \{\dot{F}_p\} + \{\dot{F}_T\} + \{\dot{F}_\sigma\}$$

where:

$[K_m]$ = Membrane Stiffness Matrix

$[K_b]$ = Bending Stiffness Matrix

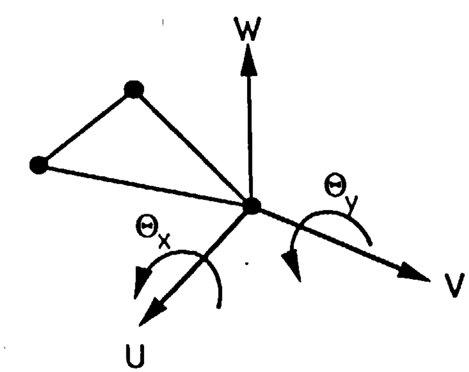
$[K_g(\dot{N})]$ = Geometric Stiffness Matrix

N = Membrane Forces

$\{\dot{F}_p\}$ = Plastic Strain

$\{\dot{F}_T\}$ = Temperature

$\{\dot{F}_\sigma\}$ = Surface Tractions



DKT Plate Bending Element

FINITE ELEMENT APPLICATIONS

VALIDATION STUDIES:

1. CLASSICAL ELASTIC PLATES (COMPLETED)
2. ELASTIC VON KARMAN PLATES
    - -LEVY AND CLOUGH FOR PRESSURE LOADS (CURRENT)
    - -GOSSARD, ET AL. FOR HELDENFELS PLATE (PLANNED)

ELASTIC AND INELASTIC STUDIES (PLANNED):

3. SLOWLY HEATED HASTELLOY PANELS
4. RAPIDLY HEATED HASTELLOY PANELS
5. ALUMINUM ALLOY PANELS

BODNER-PARTOM CONSTITUTIVE MODELS

APPROACH FOR CONSTITUTIVE MODEL DEVELOPMENT

1. Review Bodner-Partom Model
2. Study SwRI Experimental Procedure
3. Simulate Material Constant Determination Procedure for B1900+Hf
4. Begin Experimental Program for
   - Hastelloy-X
   - 8009 Aluminum Alloy
5. Validate Bodner-Partom Model

ESSENTIAL EQUATIONS FOR THE UNI-DIRECTIONAL BODNER-PARTOM CONSTITUTIVE MODEL

1. $\dot{\varepsilon}_t = \dot{\varepsilon}_e + \dot{\varepsilon}_p$

2. $\dot{\varepsilon}_p = (2/\sqrt{3})D_0\{\sigma/|\sigma|\}\exp\{-.5(Z/\sigma)^{2n}\}$

3. $Z = Z^I + Z^D$

4. $\dot{Z}^I = m_1(Z_1 - Z^I)\dot{W}_p - A_1 Z_1\{(Z^I - Z_2)/Z_1\}^{r_1}$

5. $\dot{Z}^D = m_2(Z_3 - Z^D)\dot{W}_p - A_2 Z_1\{Z^D/Z_1\}^{r_2}$

6. $\dot{W}_p = \sigma(\dot{\varepsilon}_p)$

MATERIAL CONSTANTS IN THE BODNER-PARTOM CONSTITUTIVE MODEL

TEMP. INDEPENDENT

D_0 : Limiting shear strain rate [sec^{-1}]

Z_1 : Limiting (maximum) value of Z^I [psi]

Z_3 : Limiting (maximum) value of Z^D [psi]

m_1 : Hardening rate coeff. of Z^I [psi^{-1}]

m_2 : Hardening rate coeff. of Z^I [psi^{-1}]

TEMP. DEPENDENT

Z_0 : Initial value of isotropic hardening variable [psi]

Z_2 : Fully recovered (minimum) value of Z^I [psi]

n : Kinetic parameter

A_1 : Recovery coeff. for Z^I [psi]

A_2 : Recovery coeff. for Z^D [psi]

r_1 : Recovery exponent for Z^I

r_2 : Recovery exponent for Z^D

PROCEDURE FOR OBTAINING BODNER-PARTOM CONSTANTS (SwRI)

1. Conduct a series of Multi-Strain-Rate Uniaxial Tensile Tests

2. Obtain a Polynomial that approximates σ vs. ε_p

3. Using the polynomial data, generate a plot of γ vs. σ

   where $\gamma = (1/\sigma)(d\sigma/d\varepsilon_p)$

4. Obtain m_1 and m_2 from the slopes of γ vs. σ

5. Set D_0 (usually taken to be 1×10^4 sec^{-1})

6. Obtain n from saturation stress (σ_s) vs. strain rate

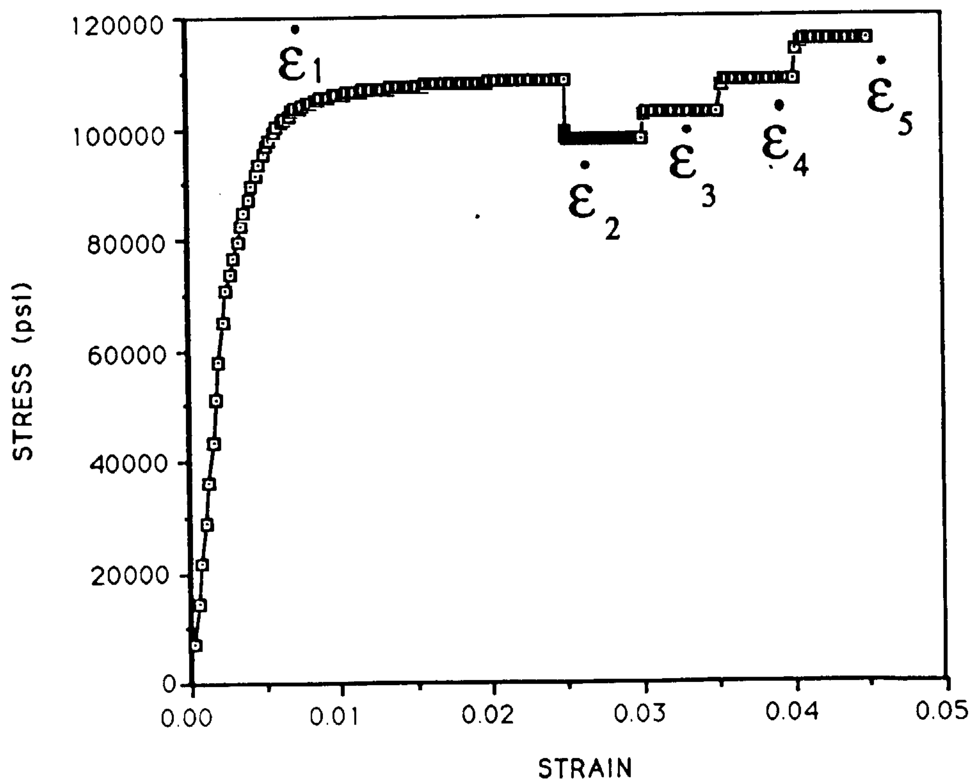
7. Calculate sum of Z_1 and Z_3 from σ_s, n, and $\dot{\varepsilon}_p$

8. Obtain Z_0 from 0.2% offset yield stress ; Set Z_2=Z_0

9. Calculate Z_1 from σ_{yield} and σ_s ; Obtain Z_3

10. Calculate $A_1(=A_2)$ and $r_1(=r_2)$ from slow rate (ε_2) tensile data

SIMULATED TENSION TEST WITH STRAIN RATE JUMPS



$\dot{\varepsilon}_1$ = 1E-04 1/sec

$\dot{\varepsilon}_2$ = 1E-06 1/sec

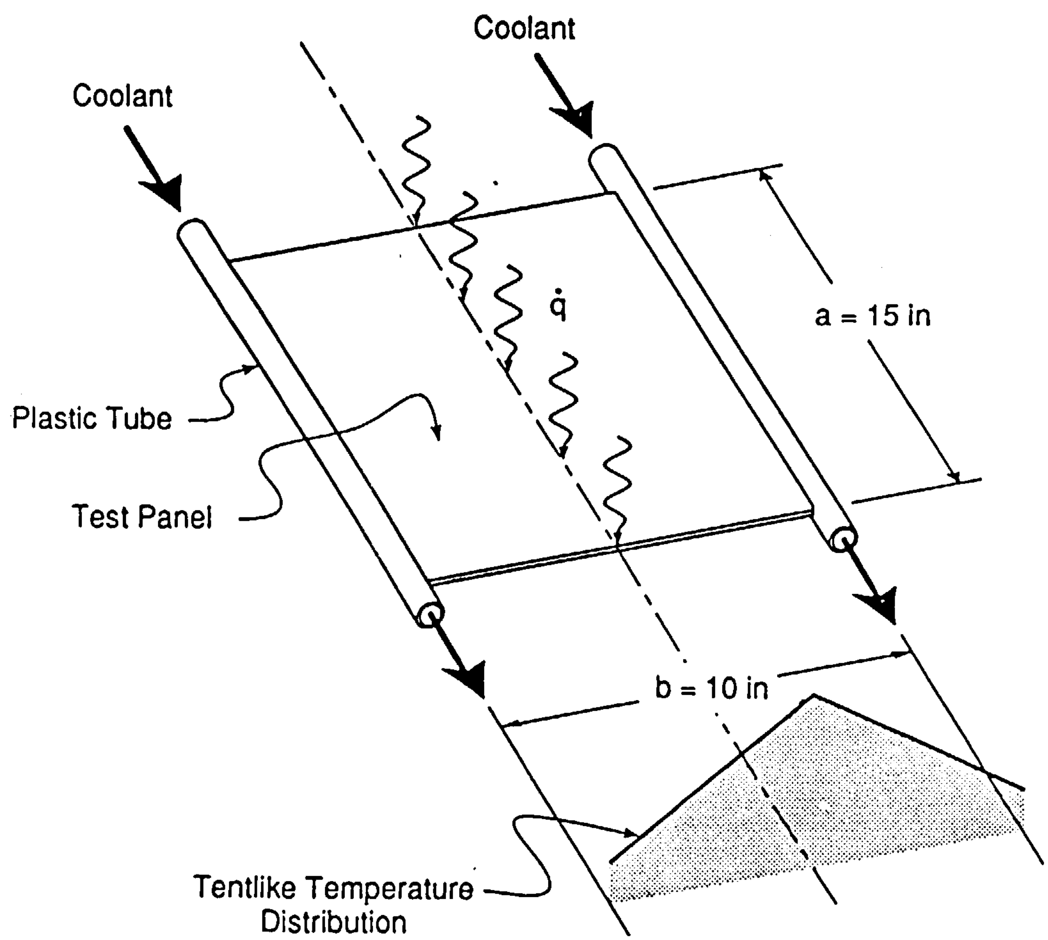
$\dot{\varepsilon}_3$ = 1E-05 1/sec

$\dot{\varepsilon}_4$ = 1E-04 1/sec

$\dot{\varepsilon}_5$ = 1E-03 1/sec

THERMAL-STRUCTURAL TESTS OF PANELS

HELDENFELS PROBLEM



EXPERIMENTAL PROGRESS

PHASE 1 - INSTRUMENTATION OF HASTELLOY PANELS

- *Measured Hastelloy-X Panels' Initial Deformations*
- *Installed PC Based Data Acquisition System*
- *Installed Strain Gages and Thermocouples*
- *Installed LVDTs To Measure Out of Plane Displacement*

PHASE 2 - DESIGN AND FABRICATE TEST FIXTURE

- *Incorporated Line Heater*
- *Installed and Tested Coolant Tubes and Chill Water System*
- *Provided Four Point Supports For Test Panel*
- *Provided Mounts for LVDTs*

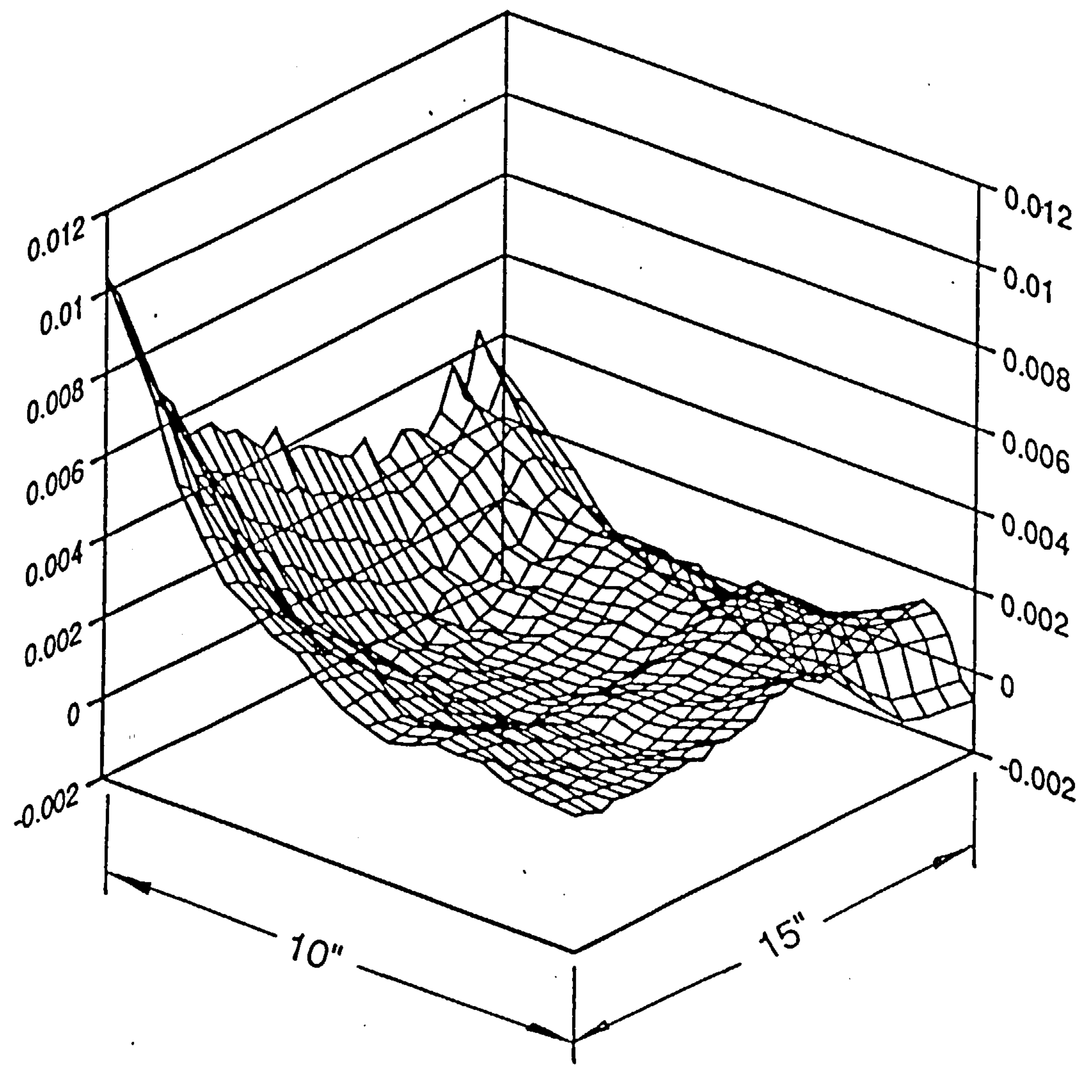
PHASE 3 - BEGAN TESTING HASTELLOY-X PANELS

- *Using Line Heater*
- *Evaluated Temperature Distribution*
- *Evaluated LVDTs Data*

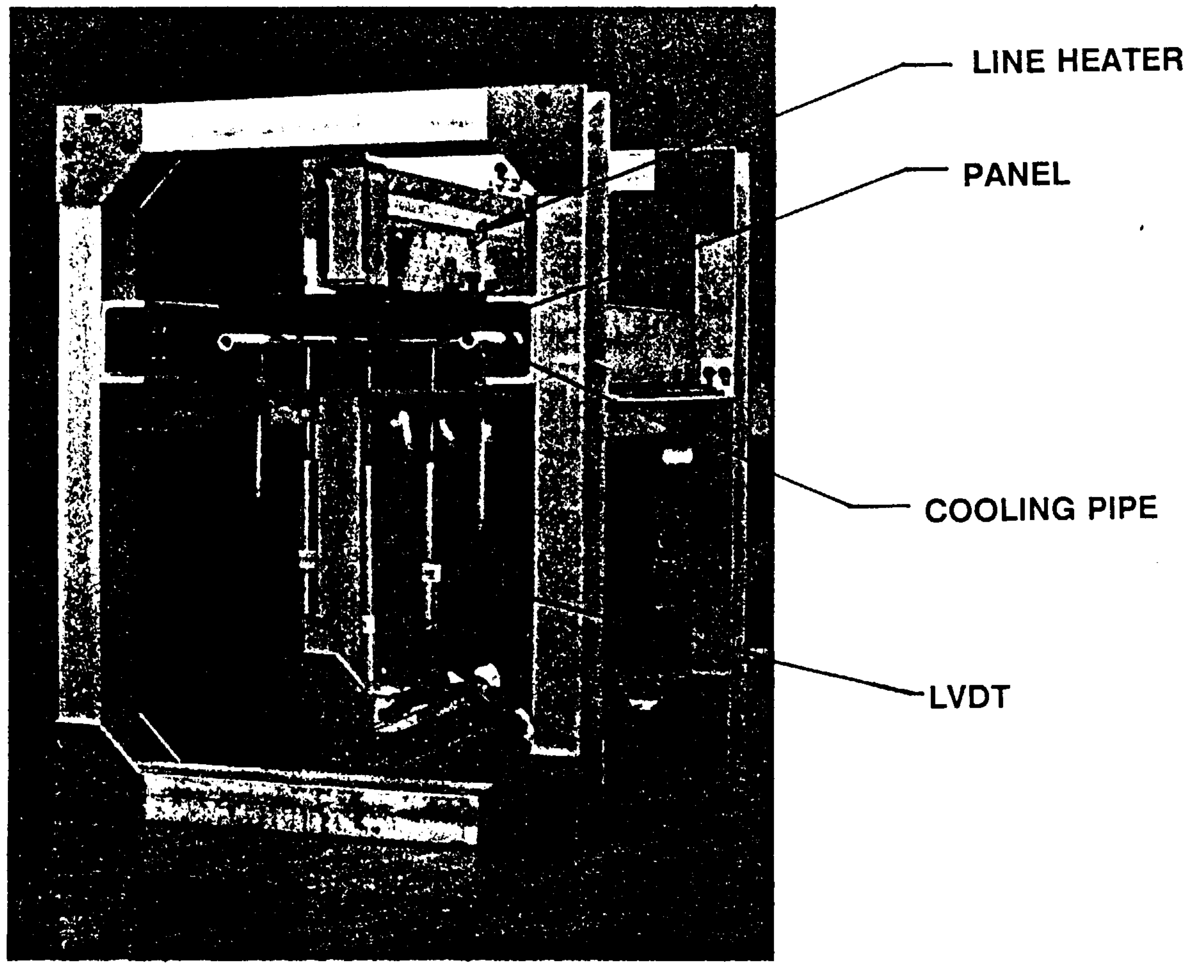
Color Slides Will Show The Experiments

HASTELLOY-X PANEL

MEASURED INITIAL DISPLACEMENTS



TEST FIXTURE FOR THERMAL-STRUCTURAL TESTS OF PANELS



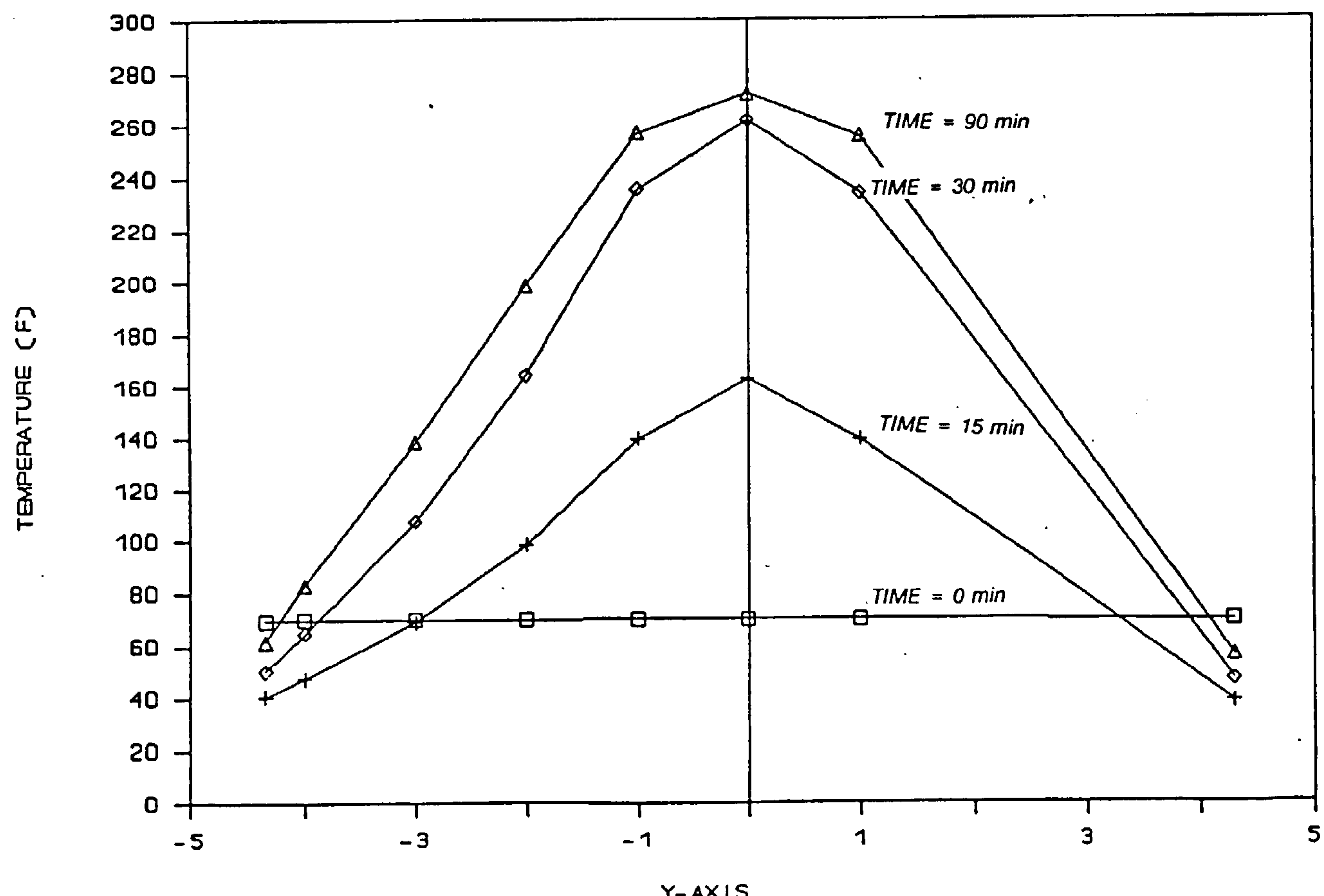
INITIAL TEST RESULTS

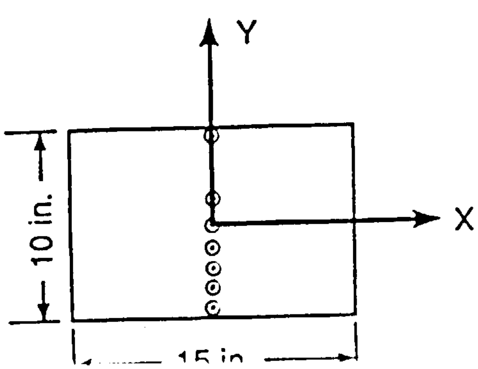
FOR SLOWLY HEATED HASTELLOY-X PANEL

- *TEMPERATURE DISTRIBUTIONS*
- *TEMPERATURE HISTORIES*
- *DISPLACEMENT HISTORIES*

EXPERIMENTAL TEMPERATURES FOR TEST PANEL

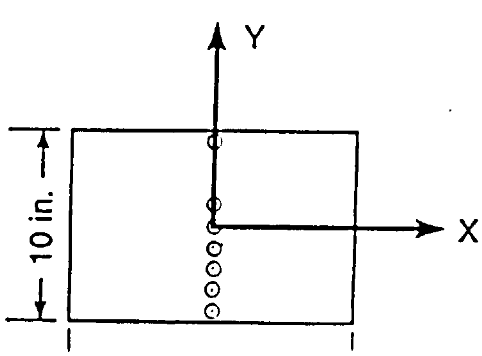
TEMPERATURE PROFILE ALONG Y AXIS

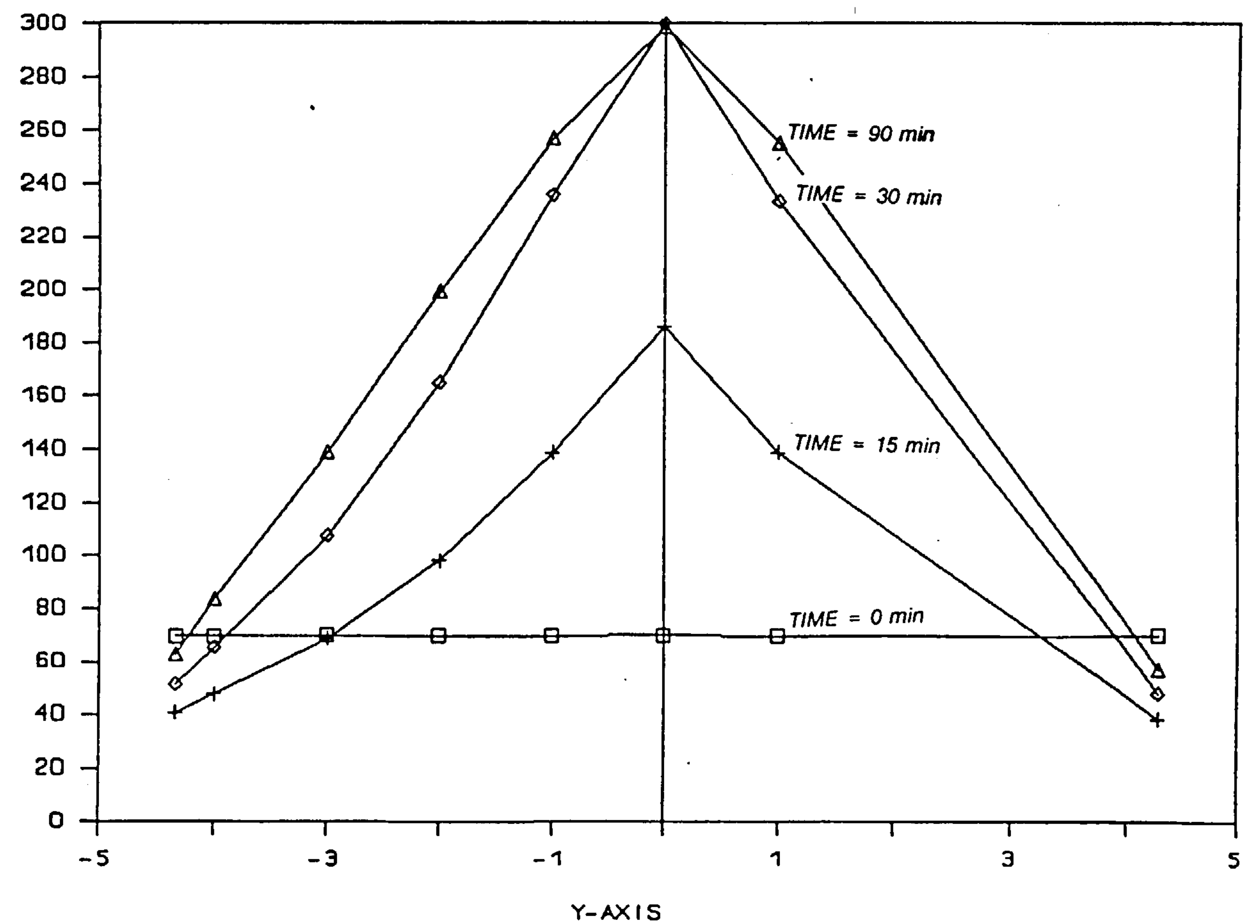




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

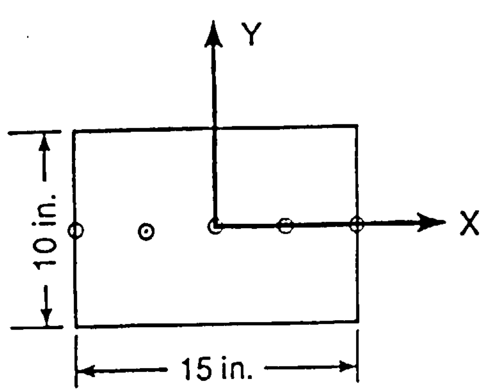
TEMPERATURE PROFILE ALONG Y AXIS (WITHOUT LVDT)

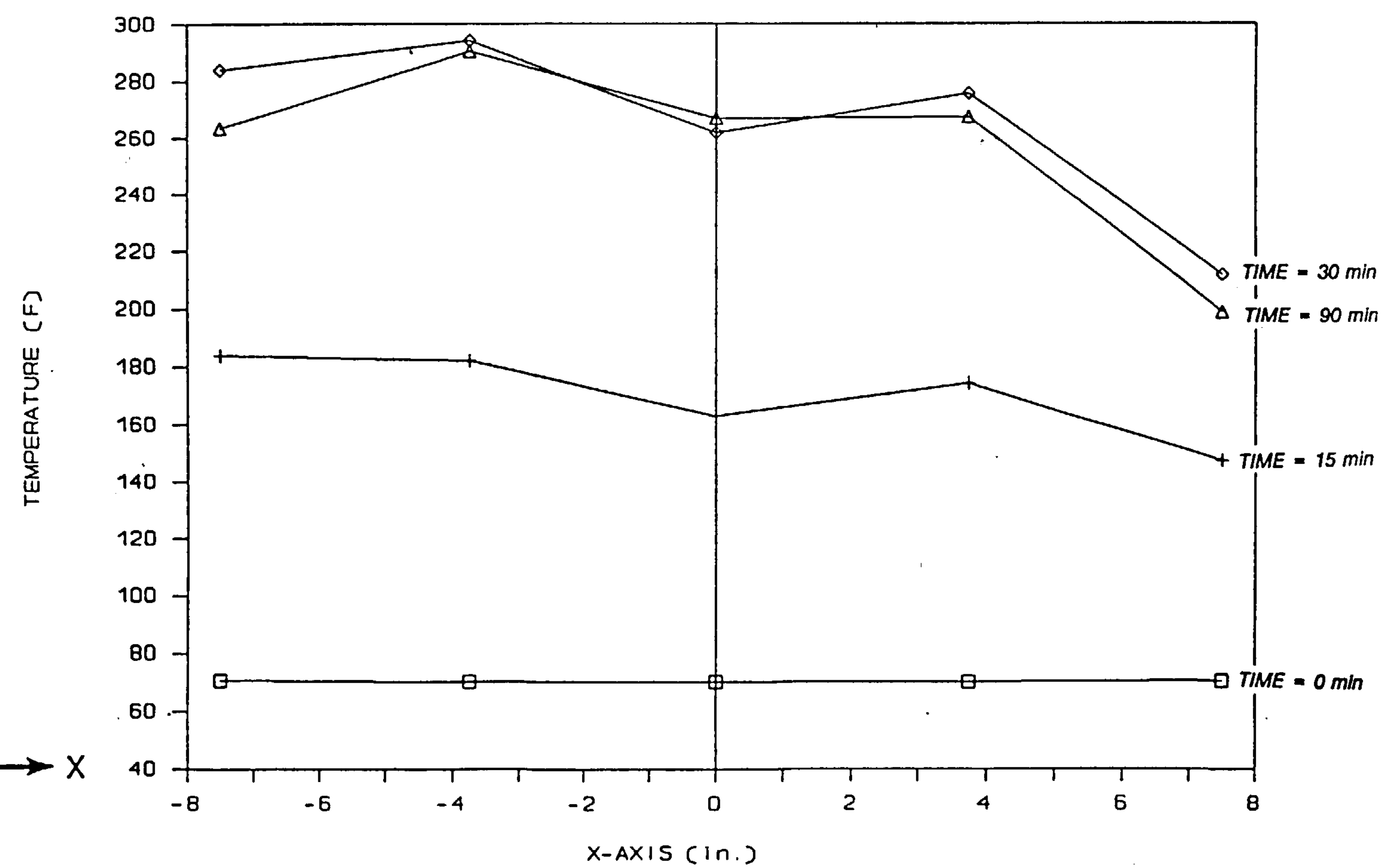




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

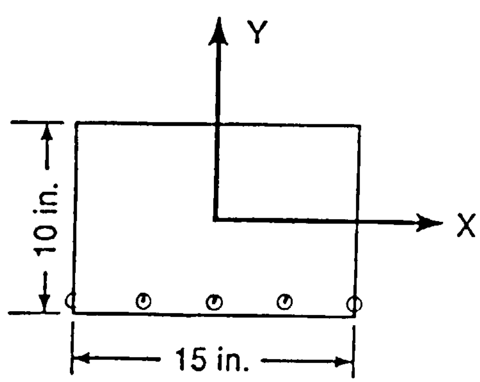
TEMPERATURES TAKEN ALONG X AXIS

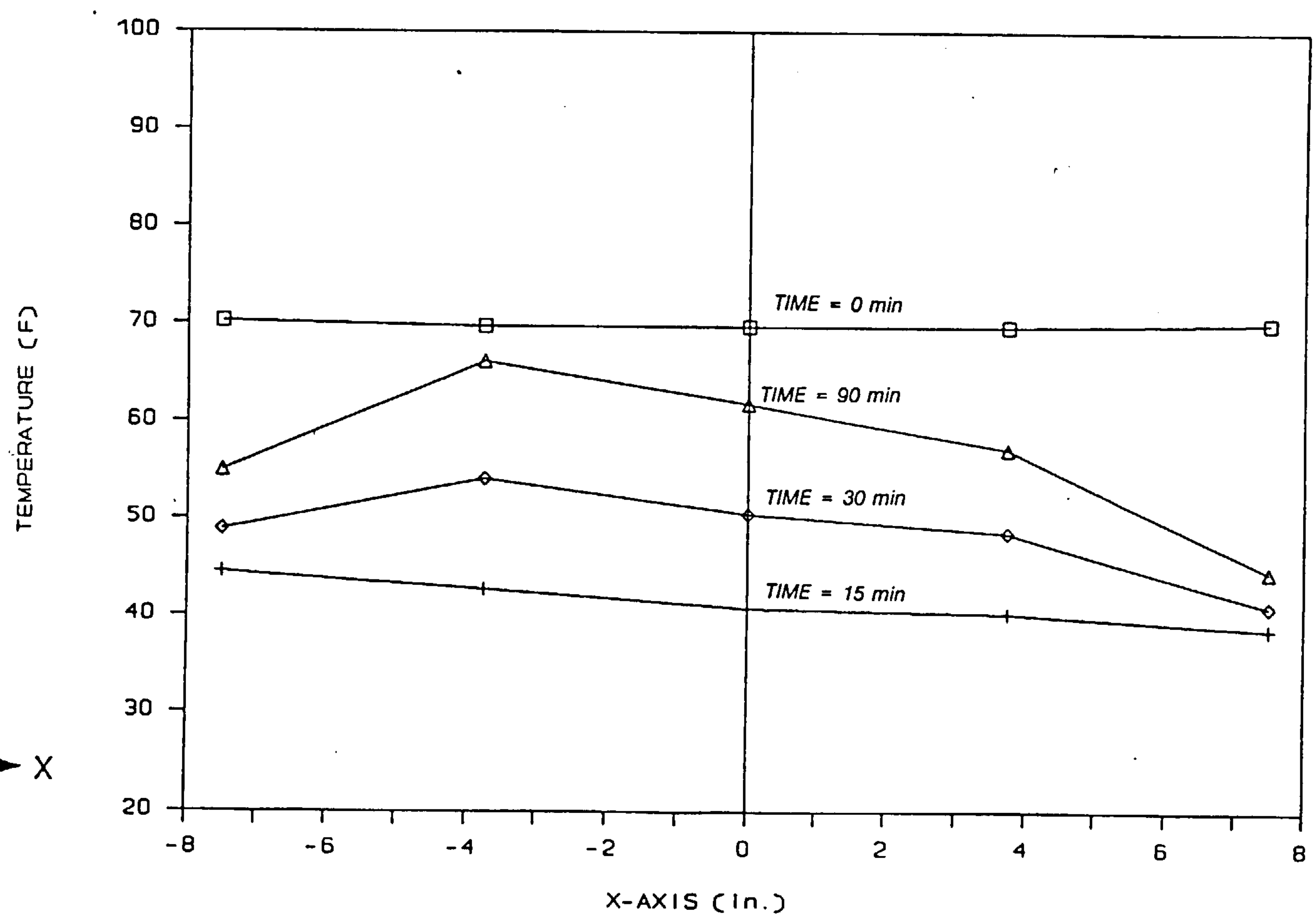




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

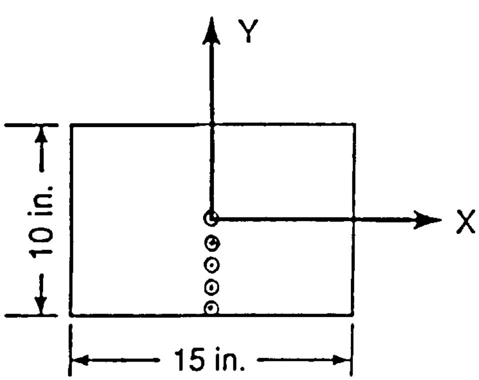
TEMPERATURES TAKEN NEAR THE COOLED EDGE ($Y = -4.3$)

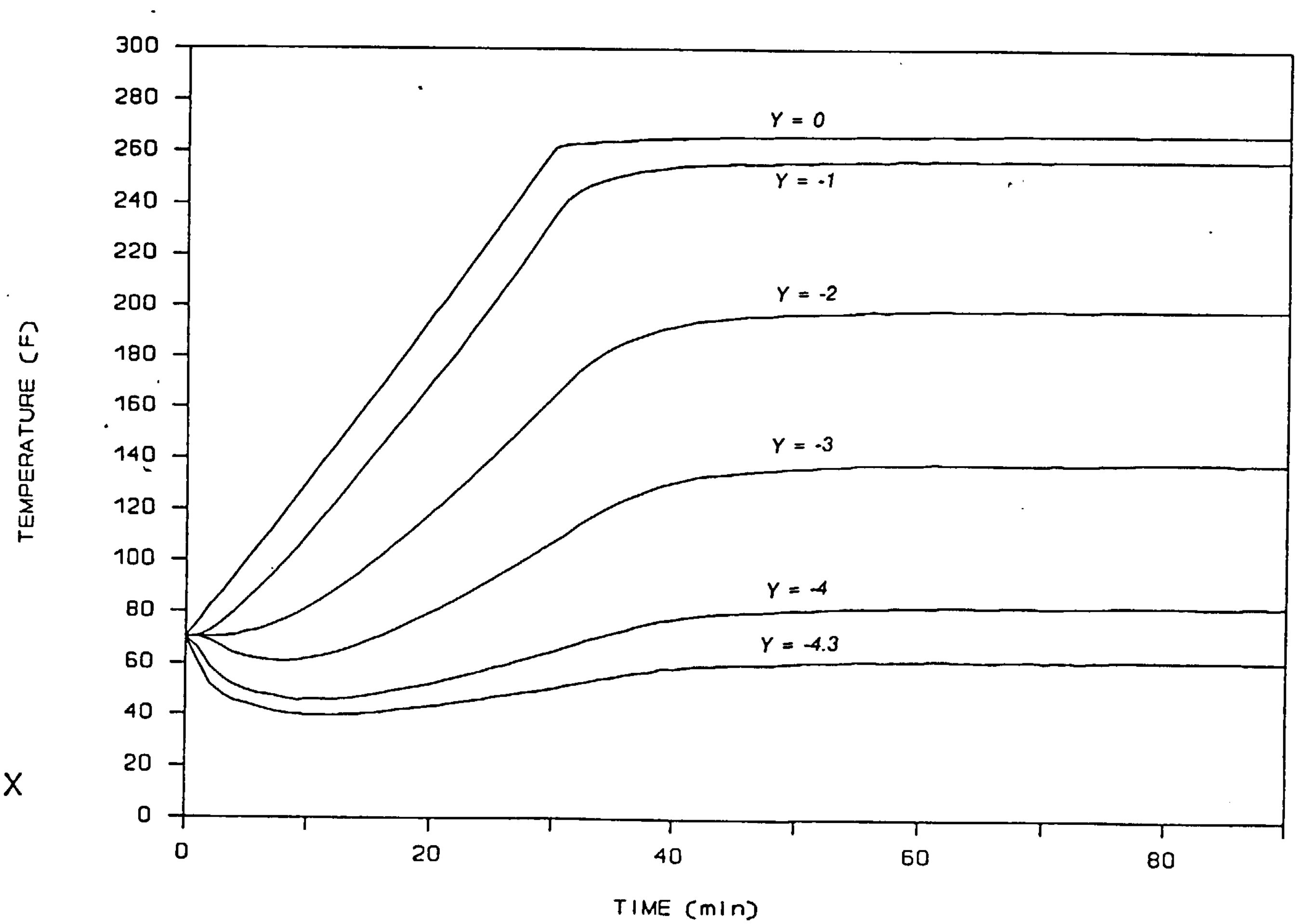




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

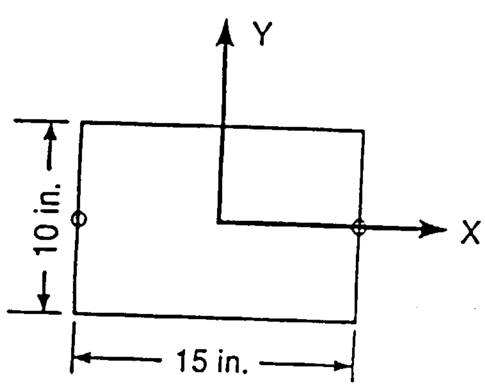
TEMPERATURES TAKEN ALONG Y AXIS VARYING WITH TIME

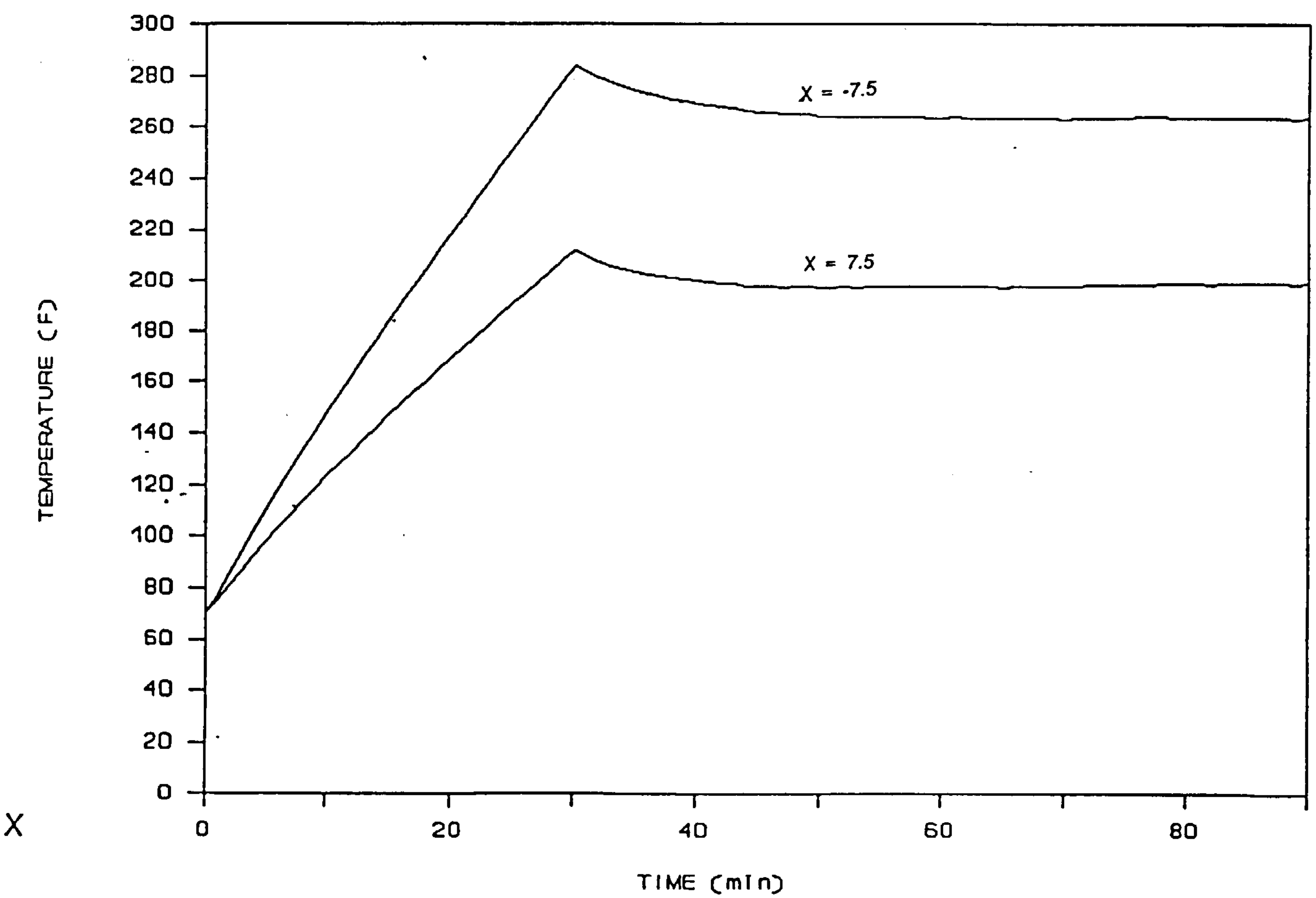




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

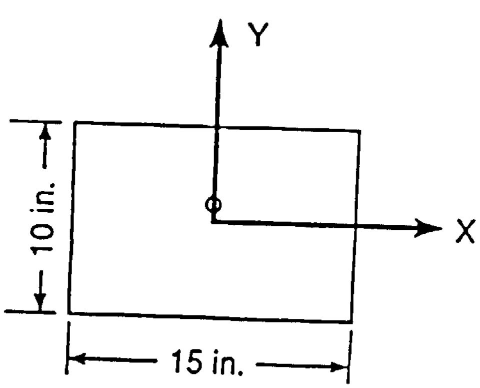
TEMPERATURES TAKEN AT X = $\underline{+}$7.5, Y = 0

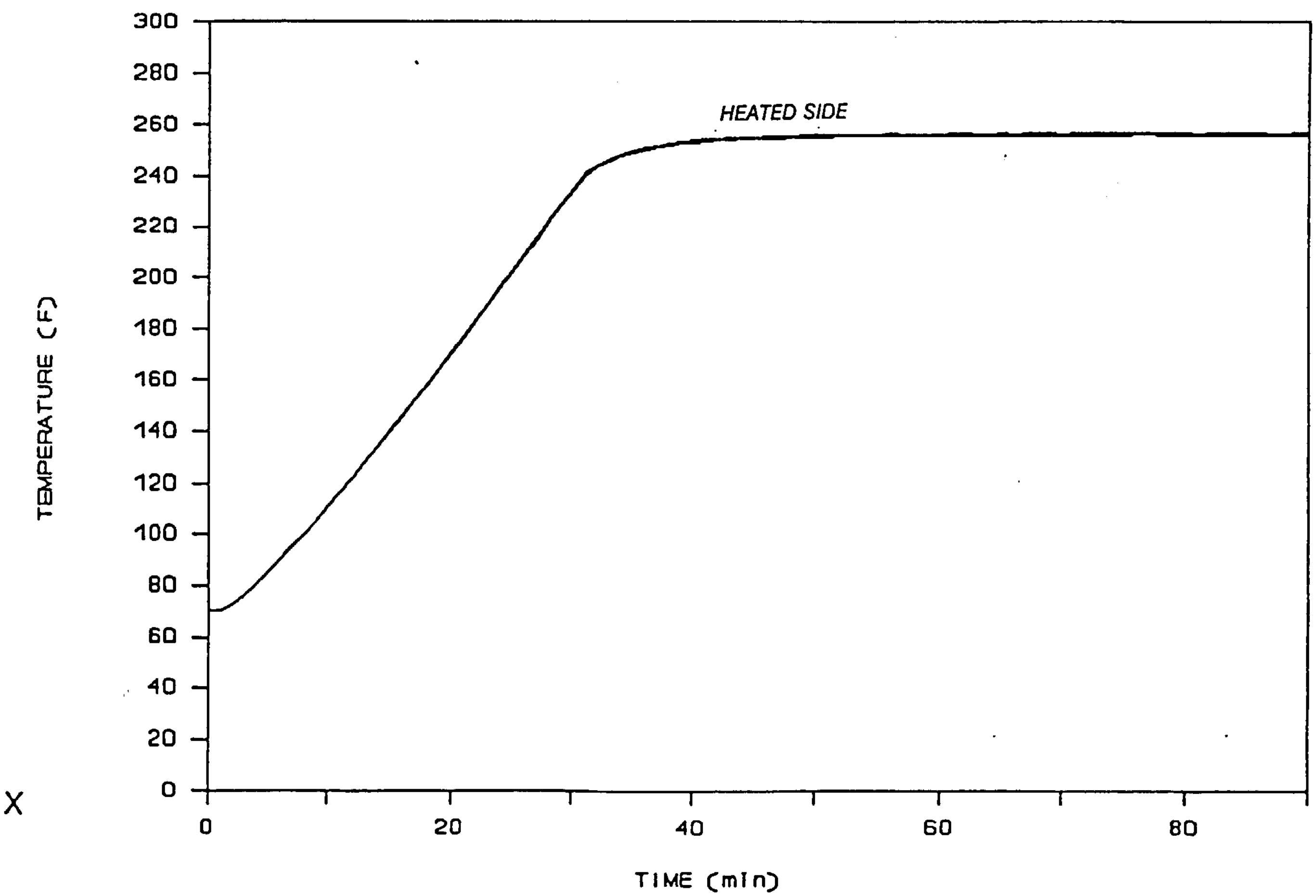




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

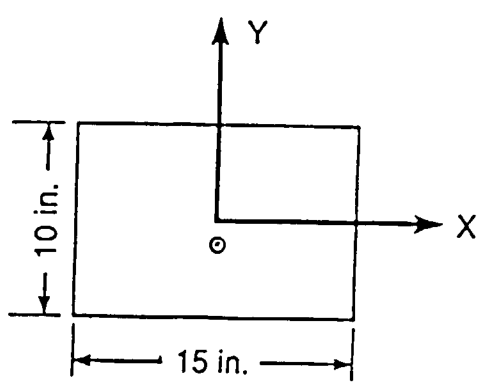
THROUGH THE THICKNESS TEMPERATURE VARIATION (X = 0, Y = 1)

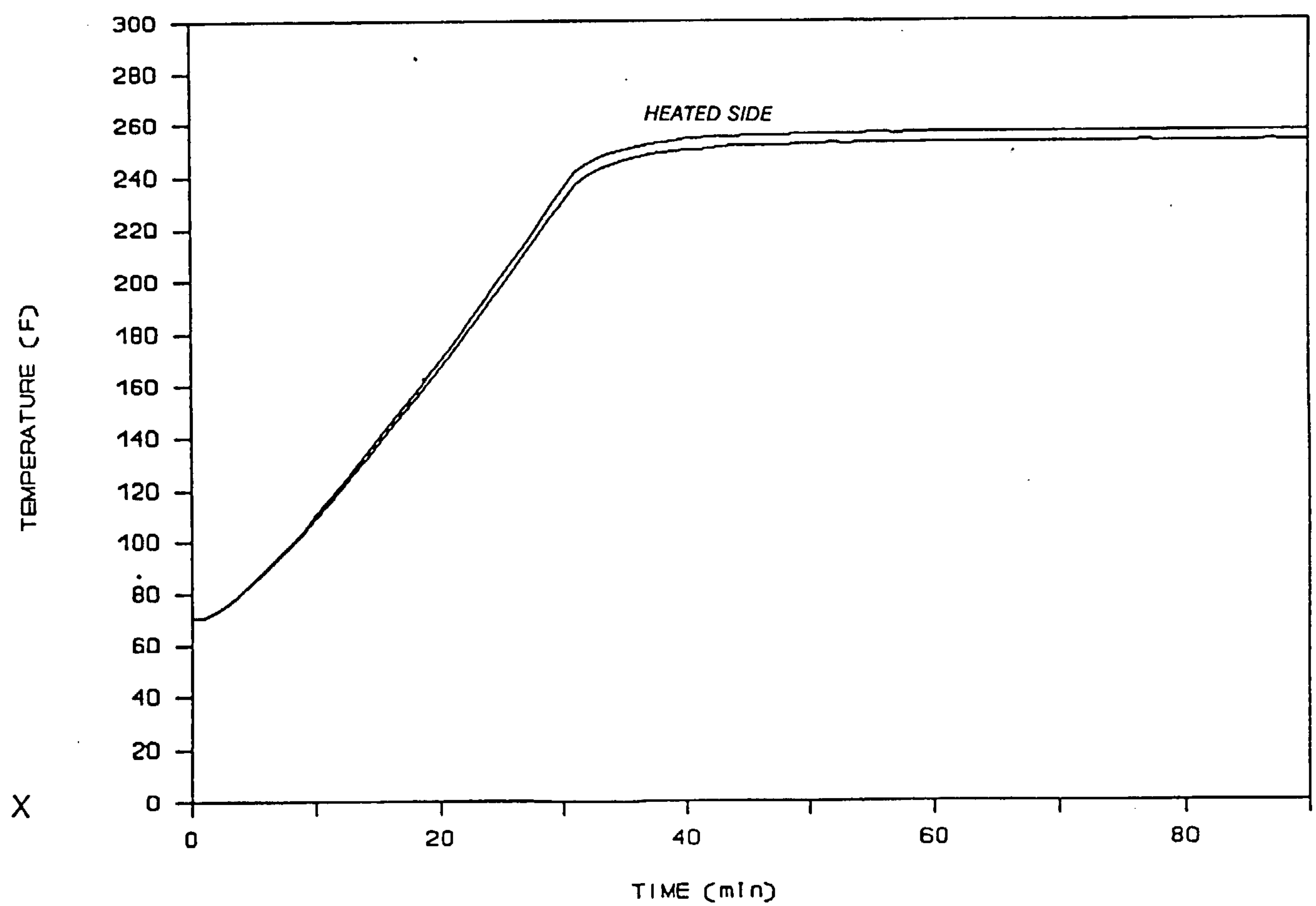




EXPERIMENTAL TEMPERATURES FOR TEST PANEL

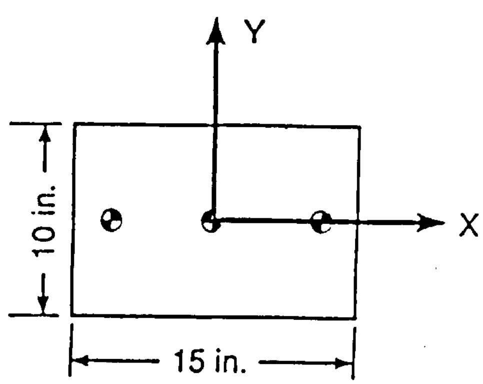
THROUGH THE THICKNESS TEMPERATURE VARIATION (X = 0, Y = -1)

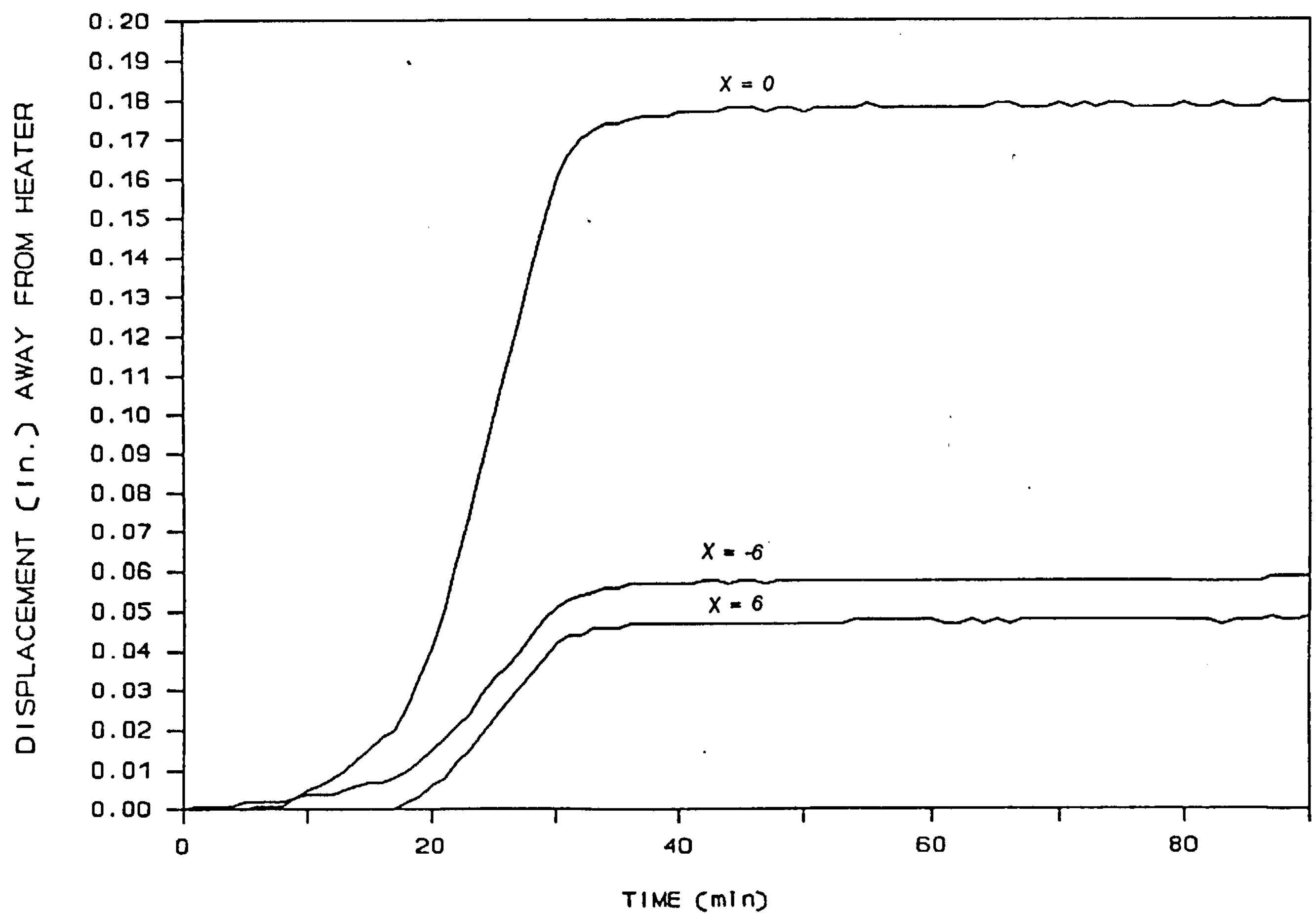




EXPERIMENTAL DISPLACEMENTS FOR TEST PANEL

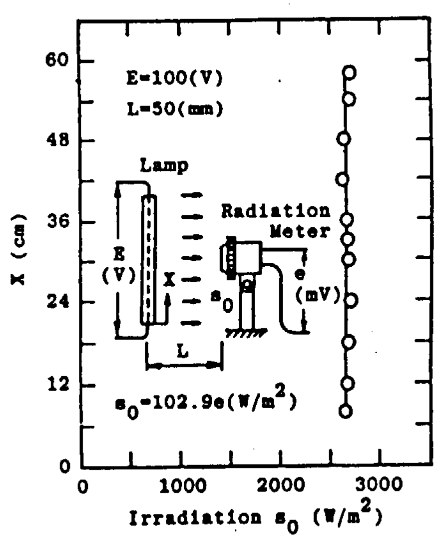
DISPLACEMENT OF THE PANEL ALONG X AXIS

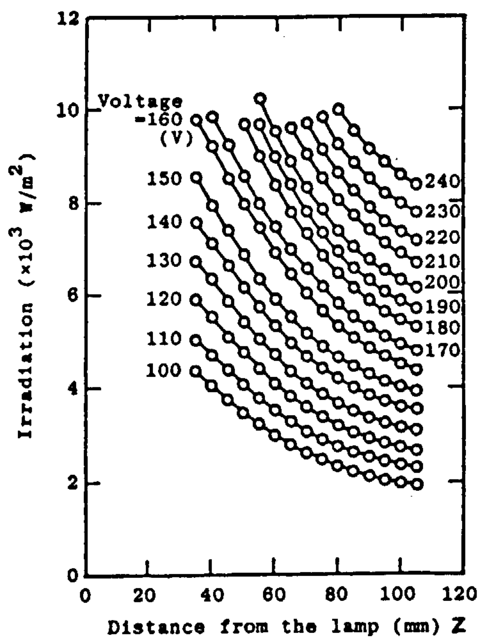




HEAT LAMP INCIDENT FLUX VARIATIONS

- PRELIMINARY TESTS INDICATE SIGNIFICANT FLUX VARIATION IN X-Y FOCAL PLANE
- SUMI (REF. 6) FOUND MAJOR VARIATION OF FLUX WITH DISTANCE Z FROM LAMP

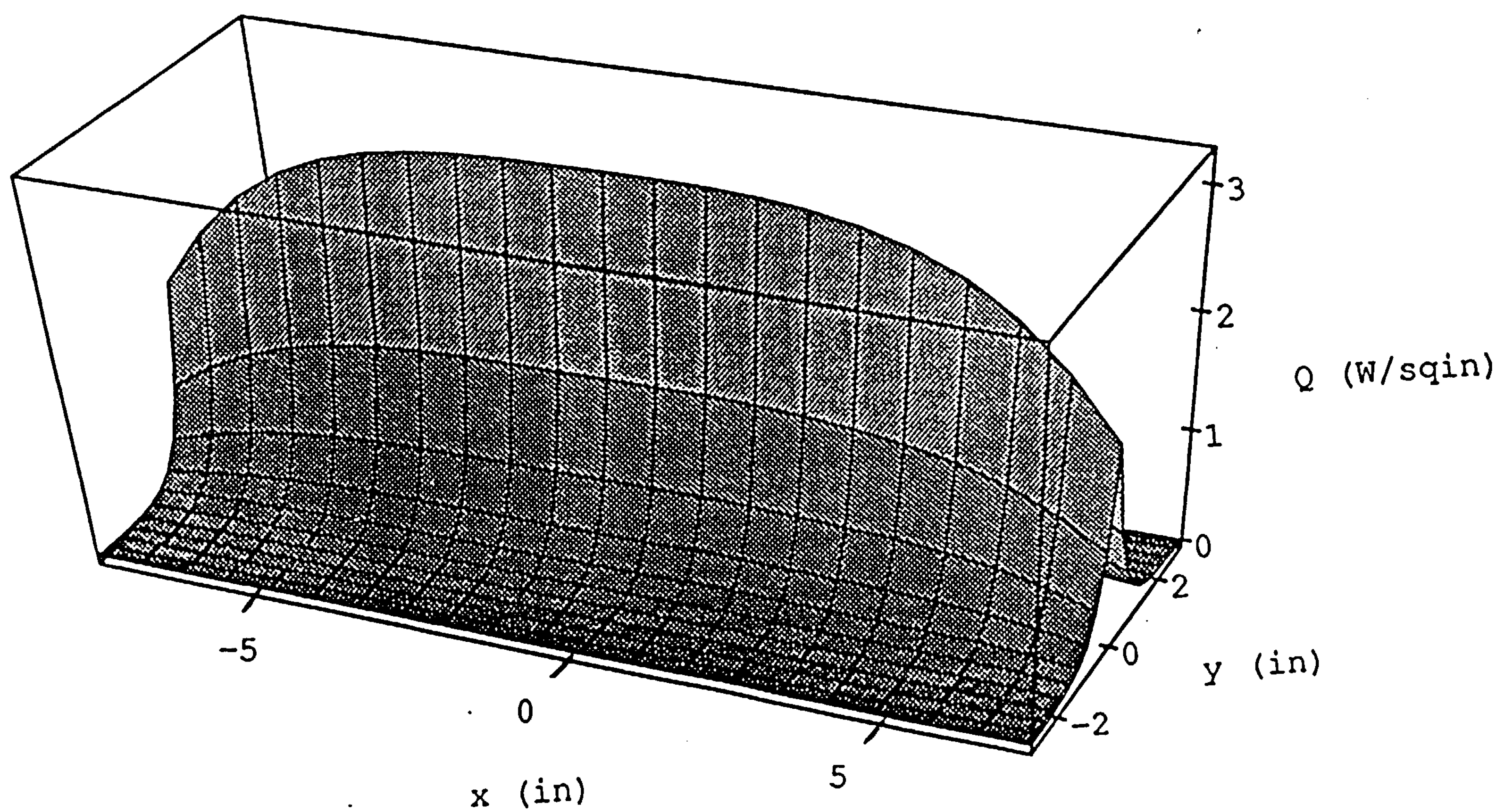




- DEPENDENCE OF FLUX ON Z COULD COUPLE THERMAL AND STRUCTURAL RESPONSE
- AUTOMATED "X-Y-Z" FLUX MEASUREMENT FIXTURE UNDER DEVELOPMENT

LINE HEATER MEASURED

INCIDENT HEAT FLUX AT FOCAL PLANE



FUTURE RESEARCH PLANS

- *LAMP CHARACTERIZATION TESTS*
- *ACQUIRE STRAIN GAGE DATA ACQUISITION SYSTEM*
- *CONTINUED TESTS OF HASTELLOY-X PANELS*
- *TEST PANEL WITH STRAIN GAGES*
- *BEGIN CORRELATION WITH ANALYSIS*

CONCLUDING REMARKS

Recent progress of a research program focused on understanding the thermoviscoplastic behavior of structural panels is described. The program has three tasks: (1) finite element simulations of nonlinear material and geometric behavior, (2) experimental determination of parameters for the Bodner-Partom constitutive models of panel materials, and (3) thermal-structural tests of panels subjected to localized heating.

Plane stress finite element computations are providing insight into panel behavior under different experimental conditions and have shown the importance of thermal loading rates. Finite element analysis of nonlinear panel bending is under development. This capability will permit the simulation of the panel tests and direct correlation of predicted displacements and strains with measured values.

A research task focused on the experimental determination of the constitutive model parameters was recently initiated. This task will provide data for the panel materials for the range of temperatures and strain rates to be used in the thermal-structural test program. Initial tests will be conducted for the available Hastelloy X material; later tests will characterize the 8009 aluminum alloy as material becomes available.

Thermal-structural testing has progressed with the design and fabrication of a panel test fixture. The fixture supports the quartz lamp line heater, the coolant system and panel insulation. It also provides point supports for a panel and supports for LVDTs to measure panel displacements. Preliminary tests have measured Hastelloy-X panel temperature and displacement histories. Unexpected variations of panel temperatures appear to be related to nonuniform incident panel heat fluxes. An experimental program to investigate lamp heat flux variations was recently initiated.

Future plans include continued development of each of the research tasks. Within the next year correlations of simulated thermoviscoplastic panel behavior with experimental data will be initiated.

REFERENCES

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